Received: 21 March 2022 | Revised: 12 December 2022 | Accepted: 3 February 2023

DOI: 10.1111/meca.12421

ORIGINAL ARTICLE

METROECONOMICA INTERNATIONAL REVIEW OF ECONOMICS WILEY

# How capital intensity affects technical progress: An empirical analysis for 17 advanced economies

**Alessandro Bellocchi**[1] | **Giuseppe Travaglini**[1] | **Beatrice Vitali**[2]

[1]Department of Economics, Society, Politics (DESP), University of Urbino Carlo Bo, Urbino, Italy

[2]Department of Economics (DSE), University of Bologna, Bologna, Italy

**Correspondence**
Giuseppe Travaglini, Department of Economics, Society, Politics (DESP), University of Urbino Carlo Bo, Via Saffi 42, Urbino 61029 (PU), Italy.
Email: giuseppe.travaglini@uniurb.it

## Abstract

In this paper we present a model of economic growth with endogenous technical progress. We test if the neoclassical growth model accepts the assumption that capital intensity affects Total Factor Productivity (TFP) in the long run. Our view takes inspiration from Kaldor's growth model of 1957 in which the *Technical Progress Function* (TPF) responds to the joint behavior of capital intensity and inventiveness. We find that "movements along a production function cannot be distinguished from shifts in this function" as formalized by the TPF. The model is tested using a Structural VAR for 17 advanced economies, over the period 1980–2020. On impact, when capital intensity improves, TFP increases sharply. This response is large and persistent over time and explains about half as much as of measured TFP. It confirms that capital intensity is an omitted variable in the traditional scheme used to estimate technical progress. Notably, the standard neoclassical growth model is not consistent with this evidence. Our analysis also shows that demand shocks can have permanent effects on output and unemployment. Finally, monetary policy helps to stabilize the business cycle, but loses its effectiveness in the long run.

**KEYWORDS**
aggregate demand, capital intensity, SVAR, technical progress function

**JEL CLASSIFICATION**
D24, E13, E24

## 1 | INTRODUCTION

Understanding the growth rate of an economy is of paramount importance to policymakers. Solow's seminal growth model (1956, 1957) is considered the starting point for any analysis of economic growth. This model and its extensions are generally regarded as satisfactory in predicting productivity and per capita income growth (Mankiw, 1995, 1997; Mankiw et al., 1992). However, it is often argued that, within the Solow model, differences in the capital-output ratios cannot explain differences in per capita income (Prescott, 1998; Romer, 1990, 1994). As it is well known, the Solow's residual - the so-called *Total Factor Productivity* (TFP)—is used as a measure of exogenous technical progress. However, economic theory does not provide any robust explanation of what determines TFP.[1] Prescott (1998, 2004) stressed that a specific theory of TFP is needed. Similarly, Meier (2001) argued that "Because of the importance of total factor productivity (…), future research will have to increase our understanding of the *unexplained residual factor* in aggregate production functions". Unfortunately, a clear-cut empirical distinction between the relative contributions of factor accumulation and technical change on productivity cannot be achieved by conventional growth accounting methods. This problem, long known in the literature, has been ignored in most recent discussions on the topic (Gundlach, 2005).

In this paper we attempt to face the issue. We employ a neoclassical growth model with endogenous technical progress to explain how technology responds to the joint behavior of capital intensity, inventiveness and (different sources of) aggregate demand. The model takes inspiration from Kaldor's growth model of 1957. However, differently from his vision, following Arrow (1962), Black (1962) and Hahn and Matthews (1964), an aggregate production function formalizes the framework.

From Kaldor we take the assumption that technical progress is endogenous, in that it is embedded in machines, and thus the rate at which it is introduced into the economy depends on capital accumulation (Antenucci et al., 2020; Schlicht, 2016). According to him, we find that "movements along a production function cannot be distinguished from shifts in this function". Therefore, we cast doubts on the idea that traditional TFP can be used as an *exogenous* measure of technical progress and give strength back to the original Kaldorian idea of a *Technical Progress Function* (TPF) which links technical progress and capital intensity in an endogenous relationship. The theoretical implications of our model are eventually tested on 17 advanced economies, over the period 1980–2020. We obtain robust estimation for the multipliers of supply and demand shocks coherent with the assumption of TPF.

Four main findings emerge from our empirical analysis. First, we corroborate the vision that "any clear sharp or clear-cut distinction between the movement along a production function with given state of knowledge, and a shift in the production function caused by a change in the state of knowledge is arbitrary and artificial" (Kaldor, 1957, 1960, pp. 264–265). Indeed, empirical analysis shows that capital intensity permanently affects technical progress. Second, exogenous "inventiveness" has transitory effects on capital intensity but has a permanent impact on labor productivity and (un)employment. Third, demand shocks, other than investment, may have *permanent* effect on productivity and (un)employment, mitigating the so called "technology unemployment" during the

[1]The concept of Total Factor Productivity (TFP) dates back to the works of Abramovitz (1956), Solow (1956) and Griliches and Jorgenson (1966) among others.

transition from one equilibrium to another. Finally, monetary shocks affect the economic cycle, but lose their effectiveness in the long term, accepting Kaldor's assumption of "purely passive rule" of monetary policy.

To test the predictions of our model, we use a Structural Vector Autoregression (SVAR) approach with a set of long-run restrictions to interpret the reduced-form residuals as different structural shocks. Then, we study the impact of a particular shock on the variables forming the VAR. Precisely, we focus on the role played by diverse shocks in explaining the joint dynamic behavior of four key variables in the modeling of technical progress, namely, capital intensity, total factor productivity, unemployment rate and real interest rate. Since we have four variables in the system, we can identify four structural shocks that are labeled as supply and demand shocks, respectively. This distinction is useful since these shocks are traditionally invoked as sources to explain the wide variety of economic growth and technical progress observed in Organization for Economic Co-operation and Development (OECD) countries in recent decades. Through the identification of those shocks, we can eventually analyze their contribution to technical progress over time.

Several studies have employed many variables to identify the structural shocks in VAR models (Antenucci et al., 2020; Balmaseda et al., 2000; Basu et al., 2006; Bellocchi et al., 2021; Gamber & Joutz, 1993; Saltari & Travaglini, 2008). Gamber and Joutz (1993), who disentangle supply shocks into two further shocks, were the precursor of this approach. We employ their methodology extending the analysis to the case of multiple demand shocks.

To build up our *complete* model we develop a two steps procedure. *As a first step,* we provide a two-sector supply-side framework to explain the long-run identifications, consistent with the idea that the explanation of economic growth requires two sectors to distinguish between traditional industries, with diminishing returns, and high-tech industries, capable of shifting the balanced growth path (Thirlwall, 1987). In this view, we assume that the innovative sector produces technical progress and that the latter is employed in the traditional one. Differently from previous literature (Aghion & Howitt, 1992; Arrow, 1962; Grossman & Helpman, 1991; Romer, 1990) the production of innovations depends directly on labor productivity in research and an input capturing "inventiveness". Further, following Kaldor's "stylized facts", we suppose that labor productivity, and intermediate inputs per worker, grow at a constant rate in the steady state. These long-run restrictions allow us to identify the supply shocks. *As a second step*, the restriction that demand shocks (other than investment) have no long-run impact on the level of capital intensity and labor productivity (as in Kaldor Mark I) could be explained in terms of a Solow growth model. However, rather than invoking the neoclassical model, we obtain the same set of restrictions from the Kaldor's growth model of 1957 where productivity depends, essentially, on capital intensity and inventiveness in the long run. As will become clear later, our modeling strategy has the advantage of overcoming the assumption that unemployment is a stationary variable, hence nesting the more general case in which unemployment may have a unit root, a feature that seems to characterize the persistence of unemployment in European countries.

Finally, identifying, as we do, supply and demand shocks together is useful to analyze another relevant issue in the behavior of technical progress, namely its cyclical component. Indeed, supply and demand shocks can lead to opposite responses of the variables over time. To the extent that business-cycle fluctuations are produced by both types of shocks, the cycle itself appears as a conglomeration of shocks. Thus, following our analysis, we can characterize the responses of technical progress in the SVAR to different structural shocks and assess which demand or supply shock is most appropriate to describe the temporal behavior of the variables in our sample of countries.

The paper is organized as follows. In Section 2 we discuss the main literature on the topic. In Section 3, we present our theoretical model, while in Section 4 we develop the empirical analysis. Finally, Section 5 provides conclusions and policy implications.

## 2 | LITERATURE

Kaldor's view of growth modeling contrasts with the neoclassical approach exemplified by Solow (1956) and Swan (1956). Solow, using the production function concluded that technical progress was responsible for more than 80% of US productivity growth during the first half of the 20th century. For Kaldor, this exercise made no theoretical sense (McCombie & Spreafico, 2016). He argued that it is not possible to separate investment in physical capital from investment in new technologies because the two measures "go hand in hand" (Schlicht, 2016). For this reason, Kaldor never really dealt with the problem. In his vision, there was nothing definable as a production function, since alternative techniques cannot be taken for granted, but discovered. Firms and employees "learn-by-doing", which is formally equivalent to discovering new activities (Arrow, 1962). Therefore, the production sets as known to the firm at each moment are not independent of the firm's decisions. As a result, no outsider can judge, by observing a firm with higher production, whether the firm has moved by using existing production sets or expanded them by incorporating new ones it was previously unaware of (Hahn, 1989).

From Kaldor's early model (Mark I)[2] the basic property of his framework "eschews any distinction between changes in techniques (and hence in productivity) which are induced by changes in the supply of capital relative to labor to those induced by technical invention or innovation, that is, the introduction of new knowledge". Kaldor made it a slogan: "movements along a production function cannot be distinguished from shifts in this function".[3] He invented the *Technical Progress Function* (TPF) wrote as $g_y = \alpha + \beta g_k$, where $\alpha$ is the exogenous component of technical progress, $y = \log\left(\frac{\text{output}}{\text{labor}}\right)$ and $k = \log\left(\frac{\text{capital}}{\text{labor}}\right)$. The idea was to avoid the distinction between movements and shifts in the production function, somewhat anticipating neoclassical "endogenous" growth models.

But, as noted by Hahn and Maede (Kaldor, 1961, p. 215), the original TPF equation can be integrated into $y = A\exp(\alpha t)\,k^{\beta}$, which is a Cobb-Douglas specification, where $y$ measures the productivity of labor, $k$ the capital- labor ratio and $A$ is a constant of integration (Eltis, 1971; Green, 1960). There is here an unexpected echo of the Solow model. Therefore, it is not surprising that when the growth rate of output depends only on the parameters of the TPF (with population constant), Kaldor concludes that an increase in savings raises the level of output per capita in the long run, *but not* its growth rate in equilibrium.[4] Kaldor was disappointed of this similarity with the neoclassical model, and later insisted that the correct formulation of his TPF required to be non-linear (McCombie & Spreafico, 2016).[5] Probably because of these problems, in 1962 Kaldor (with Mirrlees) proposed a second version of the TPF (Mark II). This was specified as a vintage growth model where the steady state growth rate of the economy is equal to the growth rate of productivity. Hereafter, this mechanism was extended in the so called Kaldor-Verdoorn law (Mark III) to include demand factors among

[2]For historical reconstruction of Kaldorian thought, see Targetti (1992).

[3]There is "no operation by which the slope of this curve could be identified" (Kaldor, 1961, p. 206).

[4]Solow himself was unsatisfied by the assumption of exogenous technological progress. Besieged by the criticisms of Robinson and Kaldor, he complained that his model made technical change "float down from the outside", as if "peculiarly disembodied" (1960, p. 90). A few years later, Johansen (1959) and Solow (1960) bypassed the problem of explaining the residual by embodying exogenous technical progress in capital.

[5]If the TPF is linear then it presupposes a Cobb-Douglas production function together with a neutral rate of technical progress; if, on the other hand, the TPF is not linear then integration in a production function is not possible (Black, 1962). This does not mean that in every single period a neoclassical production function does not exist, but the shift of the function from one period to another is not independent of the point chosen on the function itself. In other words, nonlinearity introduces "path dependence" (Kaldor, 1961).

the sources generating growth in production capacities of the economies (Kaldor, 1966, 1970, 1972, 1981; Verdoorn, 1949).[6]

Yet, there is substance to the original Kaldorian argument. The TPF is an *endogenous* mechanism which links together capital accumulation (relative to labor) and technical progress, implying that the speed with which an economic system absorbs capital depends "on its technical dynamism" where "every reorganization of production activity creates the opportunity for further change which would not have existed otherwise" (Kaldor, 1972, p. 1245).

Note that along with the academic debate, recent economic facts have suggested the need to rethink the neoclassical approach to explaining technical progress. Importantly, unlike the post-World War II period when output growth occurred at a constant rate (Kaldor, 1957), implying a constant learning curve (Arrow, 1962), the last 4 decades have shown wide fluctuations in output and inputs (Crafts & Woltjer, 2021). These facts, common to the major advanced economies, reopen the question of what proxy can efficiently capture changes in technical progress and bring the role of endogenous forces in influencing economic growth back into the economic debate (Goldin et al., 2020; Maestas et al., 2016; Travaglini & Bellocchi, 2018).

If capital accumulation (relative to labor) is the vehicle through which technologies enter into the production process, a slowdown in capital intensity may equate to a less rapid diffusion of new technologies (Cirillo et al., 2022; David, 1986). But, while embodiment effects from capital accumulation are widely believed to exist, they are difficult to quantify (Grass et al., 2012; Jarrett & Torres, 1987; Licandro, 2022).

In this paper we propose a two-sector model to measure these effects. We get a relationship consistent with Kaldor's original vision where part of the technical progress *develops out* of its exogenous component (Bairam, 1987). A crucial result of our analysis is that changes (shocks) in capital intensity operate on all margins of technical progress, shifting the economy from one equilibrium to another. Hence, technical progress is the result of stimuli that come from impulses to capital intensity and inventiveness: when capital intensity improves, output and inputs generally increase in the short run, and technical progress itself tends to increase in the long run.

We test these theoretical implications using a SVAR approach. The identification of shocks is achieved by imposing restrictions on the matrix of long-run multipliers of the estimated VAR (Antenucci et al., 2020; Balmasseda et al., 2000; Blanchard & Quah, 1989; Gamber & Joutz, 1993; Travaglini & Bellocchi, 2018). From the impulse responses we obtain estimations of the multipliers and the corresponding variance and historical decompositions.

As said above, our analysis provides information on the impacts of supply and demand shocks on the four variables forming the VAR, namely, capital intensity, TFP, unemployment rate and real interest rate. Notice that, if *exogenous* technology shocks ("inventiveness" according to Kaldor's definition) were the only impulse to drive TFP, then we would observe in the long run *absence of correlation* between TFP and capital intensity, when controlling for this latter. However, as we show below, the SVAR's impulse responses accept the null hypothesis that TFP is affected on impact and persistently by supply shocks in capital intensity, hence confirming the original Kaldor's intuition of an *inextricable* relationship between technical progress and capital accumulation. Further, our framework allows us to evaluate if changes in aggregate demand, other than investment, can affect productivity and (un)employment in the long run. While discussions about *hysteresis* do not appear relevant

[6]This relationship in a demand-driven growth context was recently analyzed by Antenucci et al. (2020) and Carnevali et al. (2020), who used a SVAR and instrumental variables, respectively. For a discussion of the implications of the Kaldor-Verdoon law, see Basu and Budhiraja (2021). Other Post-Keynesian models in which long-run growth ultimately depends on demand factors are Palley (2019), Nah and Lavoie (2019), Fazzari et al. (2020).

in the original Kaldorian approach, in which full employment is seen as a (physical) upper limit to the possibility of expanding output, this latter issue has become relevant in the more recent Kaldorian literature (Setterfield, 1993, 2002) where endogeneity and path dependence are the result of cumulative causations, giving rise to what is described as "evolutionary hysteresis".[7] Hysteresis remains also relevant in the neoclassical perspective where fluctuations in unemployment can have a permanent impact on the "natural" unemployment rate (Ball, 2009; Blanchard & Summers, 1986). Finally, relative to monetary policy, Kaldor assumes (1957) that it "plays a purely passive role" because "the interest rates … follow, in the long run … the standard set by the rate of profit obtainable on investments" (Kaldor, 1957, p. 602). We test this hypothesis in our model, and the impulse responses are consistent with it.

## 3 | THE MODEL

We assume that four structural shocks affect the movements of key variables in the model, in either the short or long run. Two shocks, labeled respectively, *Kaldor and Solow shocks* come from the *supply* side; while the remaining two come from the *demand* side and are labeled respectively, *Keynes and Friedman shocks*.[8]

Let us start with the supply shocks. We consider a two-sector model of the economy. In one sector, output is produced, while in the other technology advancement is done. We indicate with $A_t$ the level of technology at time $t$. $A_t$ is a by-product of labor productivity employed in research $Y_t/L_t$ and a component of technical progress which captures *inventiveness* $V_t$. This allows us to write the technology generating process at time $t$ as:

$$A_t = V_t^{\theta}\left(\frac{Y_t}{L_t}\right)^{\delta} \tag{1}$$

In Equation (1), $\theta$ and $\delta$ are both positive coefficients and represents the elasticities of respectively $V_t$ and $Y_t/L_t$. Notably, the fact that $\theta > 0$ states that technology increases with the stock of new ideas already discovered. Therefore, according to (1), technical progress is positively related to labor productivity and the application of new ideas. We define the long run (log) level of technical progress $a_t^*$ as:

$$a_t^* = \theta v_t^* + \delta y_t^* \tag{2}$$

where $v_t$, $y_t$ are respectively the logs of $V_t$ and $Y_t/L_t$, and $v_t^*$, $y_t^*$ are respectively the long run levels of inventiveness and productivity.

Now, let us assume that the natural level of output is determined by technology $A_t$, labor $L_t$, physical capital $K_t$ and a vector of intermediate inputs such as materials and energy $X_t$. Using a Cobb-Douglas specification, we write the production function of the aggregate economy as:

$$Y_t = A_t X_t^{\alpha} K_t^{\beta} L_t^{\gamma} \tag{3}$$

[7]We thank an anonymous referee for bringing the bibliographical references on hysteresis in the Kaldorian literature to our attention.

[8]As we were reminded by a referee, Kaldor himself was the first Post-Keynesian advocate of endogenous money. However, in this exercise we prefer to label monetary changes as "Friedman shocks" to distinguish them from the Kaldorian ones related to the technical change.

Under the assumption of Constant Returns to Scale (CRS), we derive an expression for labor productivity $Y_t/L_t$ as a function of capital intensity $K_t/L_t$ and of intermediate inputs intensity $X_t/L_t$. The production function in its intensive form can be rewritten as:

$$\frac{Y_t}{L_t} = A_t\left(\frac{X_t}{L_t}\right)^{\alpha}\left(\frac{K_t}{L_t}\right)^{\beta} \tag{4}$$

Equation (4) states that long-run movements in labor productivity can be attributed to changes in (per capita) capital, (per capita) intermediate inputs and (per capita) technology stock. In the short-run productivity may deviate from its steady state value. These deviations may arise from *permanent* shocks to the level of inputs, which lead to a shift from one equilibrium to the other or may be the result of *transitory* shocks related to aggregate demand disturbances. Thus, in our model movements in productivity stem from two different sources: *supply and demand shocks*. As we explain below, some additional variables are included in the model to capture the short run components of capital intensity and inventiveness. But at this stage, we must identify the supply shocks, that is the shocks which have permanent impact on the variables in VAR. Using the log transformation of Equation (4), the long run (log) level of productivity $y_t^*$ is:

$$y_t^* = a_t^* + \alpha x_t^* + \beta k_t^* \tag{5}$$

where $a_t^* = \log\left(A_t^*\right)$, $k_t^* = \log\left(K_t^*/L_t^*\right)$ and $x_t^* = \log\left(X_t^*/L_t^*\right)$ are the long run values of technical progress, capital and intermediate inputs intensities, respectively.

## 3.1 | Long run restrictions

The restriction that characterizes the long run behavior of output and capital per unit of labor is derived from one of Kaldor's stylized facts of economic growth (1957) used by Solow in his growth model. Essentially, in our set up, the intermediate inputs per worker and labor productivity must grow at a constant rate in the steady state. Therefore:

$$x_t^* = y_t^* + \varphi \tag{6}$$

where $\varphi$ is the steady state (log) value. Substituting (6) into (5) and solving for $a_t^*$ yields:

$$y_t^* = c_0 + c_1 k_t^* + c_2 a_t^* \tag{7}$$

where $c_0 = \alpha\varphi/(1-\alpha)$, $c_1 = \beta/(1-\alpha)$ and $c_2 = 1/(1-\alpha)$ are known coefficients (positive by assumption). Substituting (7) into (2) and rearranging we get:

$$a_t^* = f_0 + f_1 k_t^* + f_2 \upsilon_t^* \tag{8}$$

where $f_0 = \alpha\varphi\delta/(1-\alpha-\delta)$, $f_1 = \beta\delta/(1-\alpha-\delta)$ and $f_2 = \theta(1-\alpha)/(1-\alpha-\delta)$. Hence, "inventiveness" $\upsilon_t^*$– that is, the development of new ideas to the production process—determines, together with capital intensity $k_t^*$, the long run level of technical progress $a_t^*$. Expression (8) shapes in a neoclassical framework the Kaldorian idea of TPF (Kaldor, 1957, 1961).

## 3.2 | Supply shocks

In the long run, capital intensity $k_t$ and inventiveness $\upsilon_t$ evolve according to the following motion equations:

$$k_t^* = k_{t-1}^* + B_k(L)\varepsilon_t \rightarrow \Delta k_t^* = B_k(L)\varepsilon_t \tag{9}$$

$$\upsilon_t^* = \upsilon_{t-1}^* + B_\upsilon(L)\lambda_t \rightarrow \Delta\upsilon_t^* = B_\upsilon(L)\lambda_t \tag{10}$$

where $\varepsilon_t$ and $\lambda_t$ are serially and mutually uncorrelated shocks.[9] In other words, in absence of supply shocks - when $B_k(L)\varepsilon_t = 0$ and $B_\upsilon(L)\lambda_t = 0-$ the economy is in steady state. Note that the log polynomials $B_k(L)$ and $B_\upsilon(L)$ are assumed to have roots outside the unit circle. Thus, the shocks $\varepsilon_t$ and $\lambda_t$ affect the equilibrium value of $k_t^*$ and $\upsilon_t^*$ and consequently the dynamics of $a_t^*$ in the long run. We label these shocks as "supply shocks", respectively *a la* Kaldor as related to improvement in capital intensity, and *a la* Solow as related to changes in exogenous inventiveness, because have a *permanent* effect on the $k_t^*$ and $\upsilon_t^*$ levels. Hence, $\varepsilon_t$ and $\lambda_t$ can be thought as any supply shock that permanently affects the evolution of $k_t^*$ and $\upsilon_t^*$ in the long run.

## 3.3 | Demand shocks

As shown, supply shocks determine the long-run path of technical progress and some transitory deviations from the balanced growth path. However, the cyclical component of technical progress can also be influenced by the impacts of demand shocks. Following the Kaldor's vision in Mark I (1957), these kinds of shocks do not deviate *permanently* the economy from its balanced growth path. Nonetheless, they may impinge upon the cyclical behavior of the economy. Hence, if we did not consider the role of demand shocks in determining variations in the variables, we could wrongly conclude that the detected variability of the economic system, and, in particular, the one of the technical progress, would be attributable *only* to supply shocks, devaluing, by this way, the role of aggregate demand in causing variations in productivity and (un)employment, at least in the intermediate periods.

Therefore, to complete the model we consider the role of demand shocks in affecting the evolution of both capital intensity $k_t$ and technology $a_t$. However, these shocks may have even long-run effects on the unemployment rate and the real interest rate. Following this approach, we will be able to characterize *unambiguously* the response of the four variables to demand shocks. In principle, since these shocks are transitory, their effect tends to disappear over time. But if variables are not stationary, structural shocks may have long-run impact on their "natural rate" (Balmaseda et al., 2000). So, two different kind of demand shocks are included in our model; they are labeled as $\mu_t$ and $\tau_t$ respectively. The former is named "Keynesian" as it directly relates to aggregate demand shocks in labor market, while the latter can be thought of as a shock "*a la* Friedman" since it is determined by changes in monetary market. Transitory shocks move the economic system away from its trend in the short run, independently from the supply shocks $\varepsilon_t$ and $\lambda_t$.

Therefore, in the complete model the observed values of $k_t$ of $a_t$ can derive from their long run values either because of supply or demand shocks:

$$k_t = k_t^* + \Omega_k(L)[\varepsilon_t, \lambda_t, \mu_t, \tau_t] \tag{11}$$

$$a_t = a_t^* + \Omega_a(L)[\varepsilon_t, \lambda_t, \mu_t, \tau_t] \tag{12}$$

The dependence of $k_t$ and of $a_t$ on the supply and demand shocks $\varepsilon_t, \lambda_t, \mu_t, \tau_t$ allows a flexible response of the system to both long- and short-run shocks. Lastly, note that if supply shocks were the

[9] Equations (9) and (10) are the standard building blocks for modeling time series containing stochastic trends. Since we cannot forecast $k_t^*$ and $\upsilon_t^*$ perfectly, $k_t^*$ and $\upsilon_t^*$ are considered random variables. Once we learn the value of $k^*$ *and* $\upsilon_t^*$ in period $t$, $k_t^*$ *and* $\upsilon_t^*$ becomes one of the realized values from a stochastic process. This basic model is a simple random walk model, where the current value of each variable $k_t^*$ and $\upsilon_t^*$ is equal to its last period's value plus a white-noise term ($\varepsilon_t$ and $\lambda_t$) respectively. $\varepsilon_t$ and $\lambda_t$ are serially and mutually uncorrelated shocks.

only impulses, even before controlling for demand shocks, we would be likely to observe a procyclical relationship between TFP and business-cycle. Demand shocks can explain why, on the other hand, TFP may exhibit a negative correlation with the business cycle. As shown below, when demand components, rather than investment, improves, employment raises more than investment, capital intensity tends to reduce and inventiveness as well. Similarly, a positive shock to the real interest rate, decreases in the short run both profitability and investment with respect to employment, reducing, even capital intensity and the incentive to innovate. Thus, we find that both supply and demand shocks are necessary to explain the evolution of the economy, and that demand shocks are important enough at cyclical frequencies for changes in unemployment and real interest rate to make capital intensity and TFP counter-cyclical.

## 4 | EMPIRICAL METHODOLOGY

Several sources explain the cyclical and long-term variations of $k_t$ and $a_t$ (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Lucas, 1988; Romer, 1989). As stressed above, if *exogenous* technical shocks were the only impulse to drive TFP in the long run, then we would detect *absence of correlation* between TFP and capital intensity. However, aggregate data show that when capital intensity improves, output, inputs and notably TFP increase as well (Figure 1). It means that it is not possible to disentangle productivity growth into independent components where TFP can be interpreted "as the rate of technical change or, more generally, as the rate of increase in efficiency of the economy" (Felipe & McCombie, 2007).

Therefore, we test if TFP is independent from capital accumulation, using capital intensity as a tool. From our empirical analysis emerges that capital intensity is an *omitted variable* and that capital shocks (per worker) can have different effects on TFP at different frequencies. The standard neoclassical growth model is not consistent with this evidence. The evidence is instead consistent with Kaldor's model where "movements along a production function cannot be distinguished from shifts in this function".

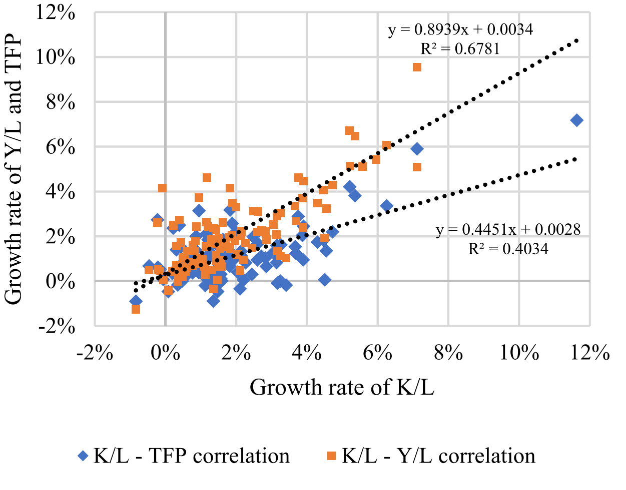


**FIGURE 1** Correlation between capital-intensity (K/L), labor productivity (Y/L) and total factor productivity (TFP). Ten-year average growth rates across decades between 1980 and 2020 for all the 17 countries in the sample (1980–2020). Outliers (observations deviating more than 3.5 IQ ranges from the median) were excluded. *Source*: Authors' elaborations on AMECO data.

To get the developments of $k_t$ and of $a_t$ over time, let us differentiate Equations (11) and (12). Then applying Equations (8)–(10) to the previous two equations we get:

$$\Delta k_t = B_k(L)\varepsilon_t + (1 - L)\Omega_k(L)[\varepsilon_t, \lambda_t, \mu_t, \tau_t] \tag{13}$$

$$\Delta a_t = f_1 B_k(L)\varepsilon_t + f_2 B_v(L)\lambda_t + (1 - L)\Omega_a(L)[\varepsilon_t, \lambda_t, \mu_t, \tau_t] \tag{14}$$

These are the two reduced-form equations which we attempt to estimate. The first one Equation (13) states that changes ($\Delta$) of $k_t$ depend on the long run effects of the shocks $\varepsilon_t$, and on all the short-run shocks. The second one Equation (14) states that changes ($\Delta$) of $a_t$ depend on both the effects of the supply shocks $\varepsilon_t$ and $\lambda_t$ and on all the demand shocks. It is interesting to note that Equation (13) implies that the first supply shock $\varepsilon_t$ has long run effect on both capital intensity and inventiveness, while the second supply shock $\lambda_t$ has no long run effects on capital intensity but maintain a long run effect on inventiveness.

Unfortunately, restriction (6) is not sufficient to identify the remaining demand shocks $\mu_t$ and $\tau_t$ in Equations (13) and (14). Indeed, we have four unknowns $(\varepsilon_t, \lambda_t, \mu_t, \tau_t)$ and only two equations. Thus, we need to add two further restrictions. We assume that aggregate demand shocks have no long run effect on both capital intensity and technical progress. This allows us to leave *unconstrained* $k_t$ and $a_t$ in the long run to test our hypotheses. Note that if these two variables are not affected by demand shocks in the long run, the cumulated effects of shocks on changes ($\Delta$) in both capital intensity and technology must be zero.

To recover short-run shocks from the VAR estimation we employ two stationary time series, namely the variation ($\Delta$) of the unemployment rate $u_t$ and the real interest rate $r_t$. Given their (tested) stationary properties, all shocks have exclusively temporary effects on $\Delta u_t$ and $r_t$. From a theoretical point of view, we interpret changes in the unemployment rate as demand shocks in labor market. These shocks, together with the monetary shocks, capture the cyclical components of the economy. Technically, this partition is necessary to evaluate the long-run impact of capital intensity on TFP. This makes it possible to write:

$$\Delta u_t = \Omega_u(L)[\varepsilon_t, \lambda_t, \mu_t, \tau_t] \tag{15}$$

$$r_t = \Omega_r(L)[\varepsilon_t, \lambda_t, \mu_t, \tau_t] \tag{16}$$

Therefore, the empirical model becomes:

$$\begin{bmatrix} \Delta k_t \\ \Delta a_t \\ \Delta u_t \\ \mathrm{r}_t \end{bmatrix} = \sum(L) \begin{bmatrix} \varepsilon_t \\ \lambda_t \\ \mu_t \\ \tau_t \end{bmatrix} \tag{17}$$

where the matrix $\sum(L)$ is a function of the polynomials $B_k(L)$, $B_v(L)$, $\Omega_k(L)$, $\Omega_a(L)$, $\Omega_u$ and $\Omega_r$. In structural VARs, shocks are identified by imposing different restrictions (Bernanke, 1986; Blanchard & Watson, 1986; Sims, 1986). We follow Blanchard and Quah (1989) and Shapiro and Watson (1988) whose identification scheme is based on constrained long run multipliers, that are the elements of $\sum(1)$. Indeed, by setting $L = 1$ in (13) and (14) we obtain that the long run multipliers from $\mu_t$ and $\tau_t$ to $k_t$ and $a_t$ are zero, and the one from $\tau_t$ is also zero on $\Delta u_t$. These assumptions imply that the cumulative effects of shocks on aggregate demand tend to zero as time passes Consistently with Kaldor and Arrow, the presence of learning-by-doing raises the possibility that demand disturbances may have some long-run effects on production and unemployment. On the empirical ground, the matrix $C(1)$ of the long-run multipliers of the estimated SVAR must be lower triangular. We estimate equations in Equation (17) under the following identification scheme:

$$\begin{bmatrix} \Delta k_t \\ \Delta a_t \\ \Delta u_t \\ \mathrm{r}_t \end{bmatrix} = \begin{bmatrix} c_{11}(1) & 0 & 0 & 0 \\ c_{21}(1) & c_{22}(1) & 0 & 0 \\ c_{31}(1) & c_{32}(1) & c_{32}(1) & 0 \\ c_{41}(1) & c_{42}(1) & c_{43}(1) & c_{44}(1) \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \lambda_t \\ \mu_t \\ \tau_t \end{bmatrix} \tag{18}$$

This system provides the long run moving average representation of our empirical model, as derived from our theoretical assumptions. The orthogonality assumption does not restrict the channels through which demand and supply shocks affect capital intensity, TFP, unemployment rate and real interest rate. We exploit this specification to identify the dynamic impact of shocks on the four variables in our SVAR.[10]

## 4.1 | Empirical model

The first step of our empirical investigation consists in estimating the following four variable VAR system:

$$A(L)X_t = \varphi_t + \omega_t \tag{19}$$

$$X_t = [\Delta k_t, \Delta a_t, \Delta u_t, r_t]' \tag{20}$$

where $X_t$ is a $(4x1)$ vector which includes the variables $[\Delta k_t, \Delta a_t, \Delta u_t, r_t]$. $A(L)$ is a $k-th$ order matrix of polynomials in the lag operator $L$ with all its roots outside the unit circle and $A(0) = I$. $\varphi_t$ is a vector of deterministic terms (including a constant), and $\omega_t$ is a vector of zero-mean independent, identically distributed (i.i.d.) random variables innovations whose covariance matrix is $\Sigma$. Omitting the deterministic components of the variables, $X_t$ can be represented as a moving average:

$$X_t = B(L)\omega_t \text{ with } B(L) = A(L)^{-1} \text{ and } B_0 = I \tag{21}$$

Equation (21) is the VAR reduced form. Here innovations ($\omega_t$) are expressed as linear combinations of structural shocks $\omega_t = K\sigma_t$, whose moving-average representation is:

$$X_t = C(L)\sigma_t \tag{22}$$

$$C(L) = B(L)K \tag{23}$$

The coefficients of $C(L)$ can be identified by introducing long-run restrictions to determine the matrix $K$ univocally. Some of these restrictions are obtained by assuming the absence of long-run impact of some shocks on some of the variables under consideration (Blanchard & Quah, 1989). If

[10]Note that, in the present model, unemployment rate and real interest rate captures the "short-period" of the Keynes-Hicks model (Hicks, 1980). Keynes (1936), Keynes and Kaldor (1937) and Kaldor (1957) made investment dependent on interest rate and output; and this give, in the IS-LM setting, a relation between real interest rate, investment, output and (un) employment. This explains why any change in unemployment and real interest rate can be seen in the "short-period" as a variation in aggregate demand out of the "long-period" equilibrium. This is, at this stage, no more than a conjecture, for we had not yet shown that the data accept this assumption. But the OECD data under inspection, and the outcomes of our SVAR model, accept the assumption.

the matrix of long-run multipliers $C(1)$ is lower triangular (i.e., *a là* Cholesky), $K$ can be obtained by estimating the VAR summarized in Equation (19) (Clarida & Gali, 1994).

## 4.2 | Results

We use annual data from the annual macro-economic database of the European Commission (AMECO), covering the period 1980–2020 for 15 advanced economies of the European Union (EU), the United Kingdom (UK) and the United States (US).[11] Capital intensity ($k$) is the (log of) the net capital stock at 2015 prices per person employed, TFP ($a$) is the (log of) total factor productivity for the total economy. We use the unemployment rate ($u$) as defined by Eurostat. Finally, the relevant variable for monetary policy is the long-term interest rate $r$.[12] This latter variable has different definitions depending on the country considered. For most of the countries, it is equal to the central government benchmark bond of 10 years (See Appendix C on Data Sources). All the series were aggregated annually and adjusted in real terms using the GDP deflator. The first difference of the (log of) original series provides the growth rate of each variable. Table 1 reports summary statistics of the data.

**TABLE 1** Summary statistics of the main variables (growth rates).

| | 1980–2008 | | | | | 2009–2020 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Var.** | **Obs** | **Mean** | **St. dev.** | **Min** | **Max** | **Obs** | **Mean** | **St. dev.** | **Min** | **Max** |
| $\Delta k$ | 28 | 1.60% | 0.009 | 0.28% | 3.20% | 12 | 0.80% | 0.009 | −0.90% | 2.08% |
| $\Delta a$ | 28 | 1.05% | 0.009 | −1.68% | 2.28% | 12 | 0.25% | 0.019 | −3.01% | 2.12% |
| $u$ | 28 | 7.65% | 0.011 | 5.70% | 9.88% | 12 | 8.89% | 0.013 | 6.78% | 10.78% |
| $\Delta u$ | 28 | 0.04% | 0.006 | −0.79% | 1.45% | 12 | 0.10% | 0.009 | −0.90% | 2.08% |
| $r$ | 28 | 3.67% | 0.017 | 0.67% | 6.26% | 12 | 1.14% | 0.018 | −1.63% | 3.62% |
| $\Delta r$ | 28 | −0.01% | 0.009 | −1.65% | 1.66% | 12 | −0.27% | 0.010 | −1.23% | 2.20% |

| | Full sample (1980–2020) | | | | |
|---|---|---|---|---|---|
| **Var.** | **Obs** | **Mean** | **St. dev.** | **Min** | **Max** |
| $\Delta k$ | 40 | 2.09% | 0.014 | −0.60% | 4.63% |
| $\Delta a$ | 40 | 1.23% | 0.016 | −4.21% | 4.25% |
| $u$ | 40 | 6.41% | 0.026 | 2.21% | 10.78% |
| $\Delta u$ | 40 | 0.08% | 0.006 | −0.90% | 2.08% |
| $r$ | 40 | 3.67% | 0.017 | 0.67% | 6.26% |
| $\Delta r$ | 40 | −0.05% | 0.009 | −1.65% | 2.20% |

*Note*: Aggregate growth rates are weighted averages (GDP at constant prices) of those observed for the countries included in the sample.

*Source*: Authors' elabouration on AMECO data.

[11]The full list of countries includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, the UK, and the US.

[12]The use of this variable was suggested to us by one of the referees to make the model closer to the original insights of Kaldor, one of the pioneers of endogenous money in the post-Keynesian literature. In an alternative exercise, we estimated the same model using broad money (M3), which includes currency and deposits with an agreed maturity of up to 2 years. We get similar results. The outcomes of this exercise are available upon request.

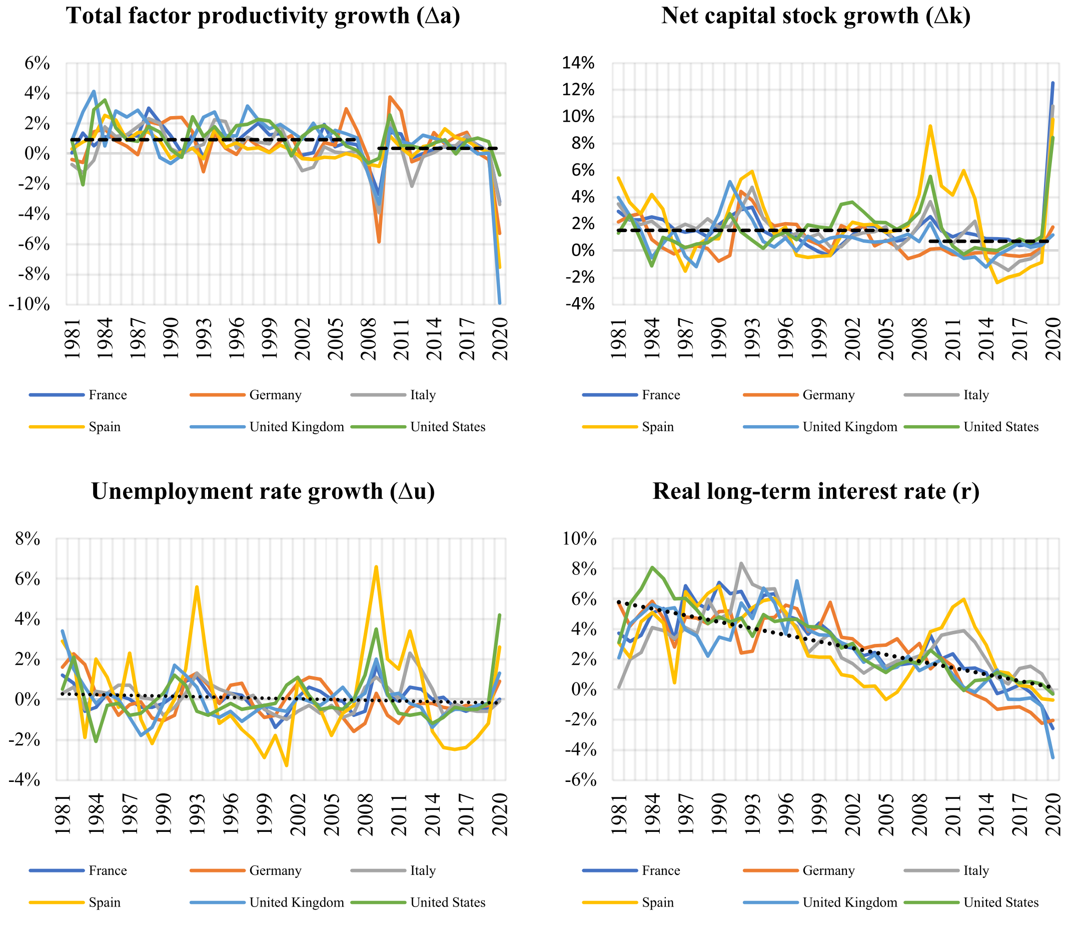


**FIGURE 2** Fluctuations and trends in the main variables (growth rates) (1980–2020). In the first two graphs ($\Delta a$ and $\Delta k$) the average before and after 2008 has been superimposed, while in the last two ($\Delta u$ and $r$) two linear trends have been superimposed. *Source*: Authors' elabouration on AMECO data.

Plotting the time path of the $\{\Delta k, \Delta a, \Delta u, r\}$ sequences provide useful information concerning outliers and structural breaks in the data which can potentially make the series not covariance stationary. This is done in Figure 2.

The marked difference in the growth rates of the net capital stock ($k$) and TFP ($a$), between the pre-crisis (1980–2008) and the post-crisis period (2009–20) is evident. Potential growth in OECD economies is estimated to have increased in recent years, although it is still weaker than before the global financial crisis (ECB, 2018). Prior to the crisis, potential growth was judged to be on a secular downward trend by many scholars (Blanchard et al., 2015; Gordon, 2017; Storm, 2022). The mean growth rates of $k$ and TFP are 1.60/1.05% and 0.80/0.25%, at an annual rate, over 1980–2008 and 2009–2020, respectively. Thus, the global financial crisis represents a major structural break in the dynamic nature of the process underlying the time series under examination—manifesting itself as a permanent jump in their mean and variance. Since there are reason to suspect a structural break, it is straightforward to employ a Chow test (Chow, 1960). The essence of the Chow test is to fit an identical ARMA model to both the pre-break and post-break data. If the two models are not sufficiently different, it can be concluded that there has not been any structural change in the data-generating process. The $p$-value of F-statistics from the Chow test results indicates value which is below the 5% critical limit, thus rejecting the null hypothesis of no structural break and confirming our expectations (Table A1 in the Appendix). Therefore, when we allow for a change in the growth rates of the variables, we remove the different sample means before estimating the vector autoregression model. Similarly, the fitted-time-trend regression coefficient for the unemployment rate is 0.028, which implies a secular increase of 1.12 p.p. over the sample period, while the slope of the same regression line for the long-term real interest is −0.0013 which results in a total decrease of 0.052 p.p (Figure A1). Since the representation we use in Section 3 assumes that both the unemployment and the real interest rate are stationary around certain levels, when we allow for secular variation in unemployment rate (level specification), the fitted-trend line is removed before VAR analysis. On the other hand, the linear trend of the real interest rate (which is employed in level being stationary) is always removed. Finally, we add two dummies to the model to exclude the two largest variations observed in the data: that of the 2008–2009 crisis and that of the 2020 COVID crisis (Juselius, 2006; Kulendran & Witt, 2001). It turns out that the moving average responses to demand and supply disturbances are close to those of the base case in their main features. Results without the inclusion of the dummy and with different data treatments are qualitatively similar and available upon request.

#### 4.2.1 | Stationarity tests

The stationarity properties of the variables included in the VAR determine the estimation, the impulse responses, and the variance decomposition of the SVAR model. The representation we use assumes that either the real interest rate, the first difference of the unemployment rate and the first difference of the logarithms of capital intensity and TFP are stationary around certain levels. Instead, the data suggest a small but steady decrease in the average change of the unemployment rate over time, a sharp decline in the real interest rate, and a change in the average growth rate of capital intensity and TFP since 2009. This raises two issues. The first is that our basic assumptions may be wrong. For instance, unemployment might be nonstationary even after differentiation, and this would affect our ability to detect any long-run effects due to supply and demand disturbances (*"hysteresis" effect*). Next, there is the issue of how to handle the apparent time trend in the real interest rate, as well as the slowdown in the growth of $k$ and $a$ after 2008. There is no clean solution for these problems, and we follow an eclectic approach that involves different specifications to strengthen the econometric results.[13]

To identify the most correct baseline model we perform traditional unit root tests. Specifically, to test for stationarity, we ran a battery of univariate unit root tests (ADF—Augmented Dickey Fuller; ADF/GLS—Augmented DF with Generalized Least Squares and KPSS—Kwiatkowski–Phillips–Schmidt–Shin). Results are reported in the Appendix. From the inspection of the data (Tables A2–A4) emerges that for most of the countries included in the sample, apart from the real interest rate, other variables can adequately be characterized as I(1) processes. In performing unit root tests, special care should be taken if a structural change is suspected, since in this case the various statistics of the Dickey-Fuller test are biased towards non-rejection of a unit root. Therefore, we split the sample into two parts (following the potential structural break identified) and tested with Dickey-Fuller on each part. However, since it is preferable to have a single test based on the full sample, we also performed a double check with Perron (1989) after allowing for a break in trend in 2008. Further, as already stressed by the literature, standard univariate unit root tests on $u$ and $r$, may not reject that $u$ or $r$ are I(1) in some countries due to lack of power, since they are notoriously known to have lower power and suffer from size distortion in the data generating process. Thus, we also test the null hypothesis in a multivariate framework, exploiting the Johansens's (1995) cointegration approach. This approach employs covariates and thus has larger

[13]See for instance Ollivaud and Turner (2015) on the long-term damage and statistical evidence for a break in average growth rates over the post financial crisis period.

power and more informative alternative hypothesis than standard univariate unit root tests. Table A5 (in the Appendix) reports the results of the Johansen test for stationarity. Considering 2 or 3 lags, none of the trace statistics reject the null hypothesis that the smallest eigenvalue is 0 at the 5% level. It means that the cointegration system is not stationary. In contrast, the differenced data support the stationarity of the cointegration system. This means that the series of $k$, $a$ and $u$ have at least one unit root and implies that to get a robust estimation of the VAR model, the first difference $[\Delta k, \Delta a, \Delta u]$ of the original series must be employed. On the other hand, the real interest rate ($r$) is stationary. Therefore, all the nonstationary time series are transformed to reach stationarity beforehand. Then, using the cumulated responses of the first differences we rebuilt $k_t, a_t, u_t$ in level and compute the new steady state of the economy after shocks.

### 4.2.2 | Impulse responses

As is well known, in the context of SVAR, model specification can have a significant effect on the size and accuracy of multiplier estimates. In addition to the structural shock identification strategy, these modeling choices include the definition of variables or whether data are smoothed prior to estimation. We explicitly integrate such uncertainty into our estimates, entertaining many models which can be obtained by combining such possible methodological choices. Therefore, in modeling the response of OCED economies to shocks and in testing the robustness of the empirical analysis, we consider three alternative VAR specifications. These allow us to cope in a flexible way with the issue of how to handle the potential time trend in unemployment and interest rates, and the apparent slowdown in productivity and capital accumulation growth after 2008. To set up the discussion, we present as a base case the estimation results that account for a change in the growth rates of capital per worker and TFP and treat unemployment rate as a difference stationary process (Specification 1). In the second case (Specification 2) we employ the same data, accounting for a secular increase (decrease) in the unemployment and the real interest rate, as captured by a fitted-linear time-trend regression line, and finally, the last specification is a standard Cholesky model—for comparison—which identifies shocks using the ordering based on the contemporaneous responses across shocks (Specification 3). We use AIC, SC and HQ tests to compute the optimal number of lags which minimize the information criterion. The absence of serial correlation in the residuals has been guaranteed by both the Box-Pierce and Ljung-Box Q-tests. In both scenarios, the dynamic structure of the VAR requires two lags and a constant.[14] Given the properties of the time series we consider two dummies, one in the deepest year of the Great Depression (2009) and one coinciding with the onset of the pandemic crisis (2020) crisis, which may well correspond to a substantial structural point break right at the end of the sample; the last observation used is for 2020. However, since the two main empirical specifications are similar in their dynamic structure and responses, we only report the statistical analysis of Specification 1.[15] The only major difference—which does not afflict the signs of long run elasticities (Table 2)—lies in the magnitude of the responses and is barely noticeable in the forecast error variance decompositions.

Figures 3–8 show the impulse response functions with 90% confidence intervals for technology and demand shocks of the four variables in the VAR for the largest OECD countries under consideration (France, Germany, Italy, Spain, UK, and the US). However, when necessary, we will extend the discussion to other countries of the sample. The black solid line describes the impulse response of a single variable to an initial one-unit shock. Green area represents the 90% bootstrap confidence interval computed using 2048 bootstrap replications.

[14]Estimation with more lags produced little difference in the results. We also experimented with omitting the last year (2020). Again, the empirical results remain virtually unchanged, indicating that the VAR setup is stable.

[15]The summary with short-term effects on the variables for different shocks is reported in Table A6.

**TABLE 2** Estimated long-run responses of variables to different shocks.

| | Austria | | | | Belgium | | | | Denmark | | | | Finland | | | | France | | | | Germany | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shock** | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* |
| Kaldor | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 |
| Solow | 0 | + | - | 0 | 0 | + | - | 0 | 0 | + | + | 0 | 0 | + | - | 0 | 0 | + | - | 0 | 0 | + | - | 0 |
| Keynes | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | + | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 |
| Friedman | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | Greece | | | | Ireland | | | | Italy | | | | Luxembourg | | | | Netherlands | | | | Norway | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shock** | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* |
| Kaldor | + | + | + | 0 | + | + | + | 0 | + | - | + | 0 | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 |
| Solow | 0 | + | - | 0 | 0 | + | - | 0 | 0 | + | + | 0 | 0 | + | - | 0 | 0 | + | - | 0 | 0 | + | - | 0 |
| Keynes | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 |
| Friedman | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | Portugal | | | | Spain | | | | Sweden | | | | UK | | | | US | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shock** | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* | *k* | *a* | *u* | *r* |
| Kaldor | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 | + | + | + | 0 |
| Solow | 0 | + | - | 0 | 0 | + | + | 0 | 0 | + | + | 0 | 0 | + | + | 0 | 0 | + | - | 0 |
| Keynes | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 | 0 | 0 | - | 0 |
| Friedman | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*Note*: Long-term elasticities estimated after 15 periods. Change in capital intensity and TFP growth in 2008/2009; real interest rate detrended.

*Source*: Authors' estimation.

### *Technology shocks a la Kaldor*

The impulse responses are consistent with our theoretical model. TFP responses positively to *Kaldorian* shocks at all frequencies, and as predicted by the model, determines the long run dynamics of technology, making it difficult to disentangle the forces moving along and shifting the technological frontier. In other words, an increase in capital intensity also increases the rate of productivity growth through its effect on technical progress. This effect is particularly evident in Greece and Ireland; it is weaker in Sweden and France and takes 6–10 periods to unfold its initial strength. The median is 8 years. In general, the increase in capital intensity has a positive impact on TFP in all the countries considered. The long run level of technology tends to raise everywhere. Notably, it is virtually zero in Italy. A widely accepted interpretation of this unexpected result is that capital accumulation in Italy, in recent decades, has occurred in the less dynamic and innovative productive sectors, such that, a process of "*unlearning*-by-doing" prevails in the aggregate economy. This empirical result confirms what has already been observed in several recent studies on the productivity slowdown in Italy where the fall in the capital-to- labor ratio has been accompanied by the dramatic recession in productivity and technical progress (Bugamelli et al., 2018; Deleidi et al., 2021; Saltari & Travaglini, 2009). Note that, the effect of Kaldorian shocks is particularly relevant in Greece (where the long-run multiplier is equal to 2.70)[16] and particularly weak in Denmark (0.35), Austria (0.33) and Belgium (0.21); the peak is reached after 2–4 periods, with a further adjustment before stabilizing at the new steady state. Kaldorian shocks generally affects positively the *unemployment rate*

[16]The full table with long-run multipliers for all countries in the sample can be found in the Appendix (Table A7).

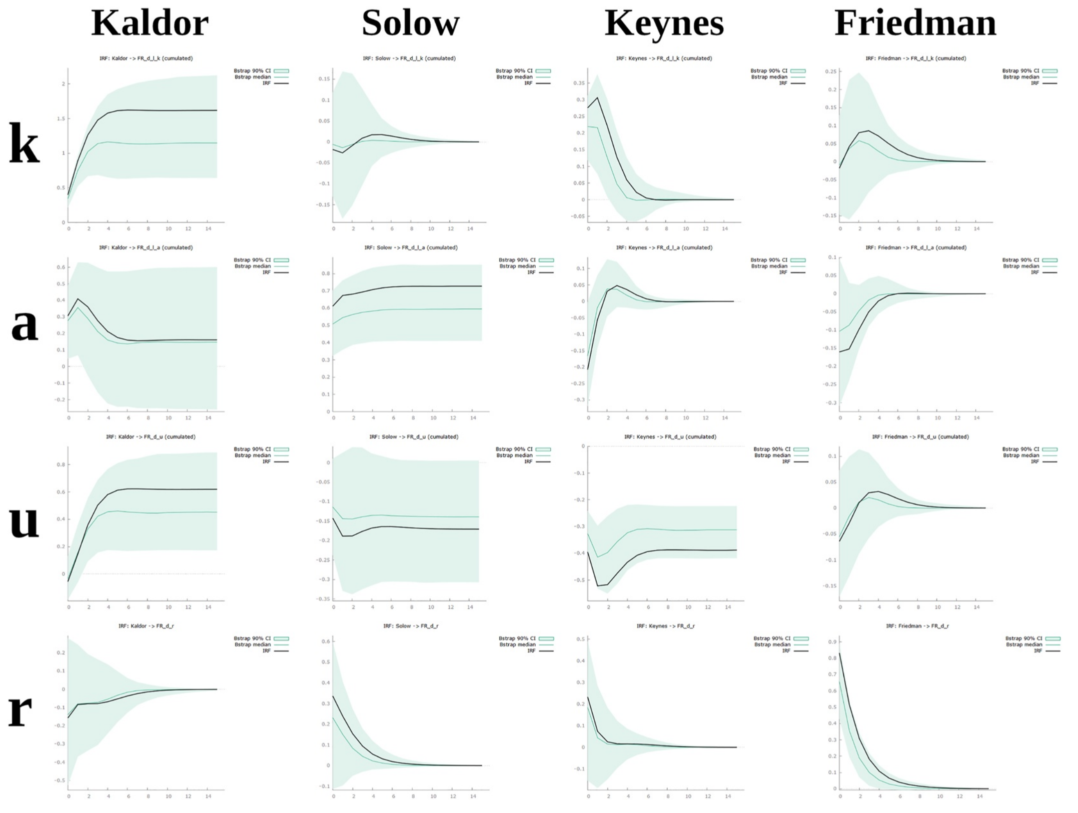


**FIGURE 3** Response to structural one S.D. innovations ±2 S.E. for France.

in the long run. This effect is strongest in Greece (3.12), Spain (2.92) and Portugal (2.42). Finally, this shock may increase or decrease the real interest rate, but the impact tends to zero in the long run.

### *Technology shocks a la Solow*

A technology shock *a la* Solow directly beats the exogenous component of *productivity*, that is, "inventiveness" in Kaldor's vision. Indeed, in its graphical representation the TPF cuts positively the vertical axis, since "there would be some positive rate of growth in output per man, even if capital-per-man remained unchanged" (Kaldor, 1961, p. 209). This is an empirical regularity known as "Horndal effect" (Lazonick & Brush, 1985), and it happens because "even a zero rate of net investment implies a certain rate of infusion of new techniques or new designs, through the replacement of worn-out capital" (Kaldor, 1961). After the exogenous Solow shock, capital intensity increases the most in Ireland (3.40) and Luxembourg (2.33). Note, however, that the short-term response of capital intensity to the same shock can be positive or negative. Specifically, we observe a rise in capital per worker in Denmark, Germany, Spain, Greece, Italy, Luxembourg, Netherlands, Portugal, Sweden, and the UK, while the same shock tends to decrease $k_t$ in the remaining countries. The peak is usually reached after 1–4 periods and is generally reabsorbed in the subsequent 2 years, sometimes with an oscillatory countermovement. The responses of the *unemployment* rate are instead ambiguous and probably they depend on the extent to which new exogenous technology is embodied in new jobs (Pissarides & Vallanti, 2007). From our outcomes results that generally an increase in TFP tends to reduce unemployment, and the effect is particularly relevant in Norway (−0.73), Germany (−0.54) and Finland (−0.51). On the other

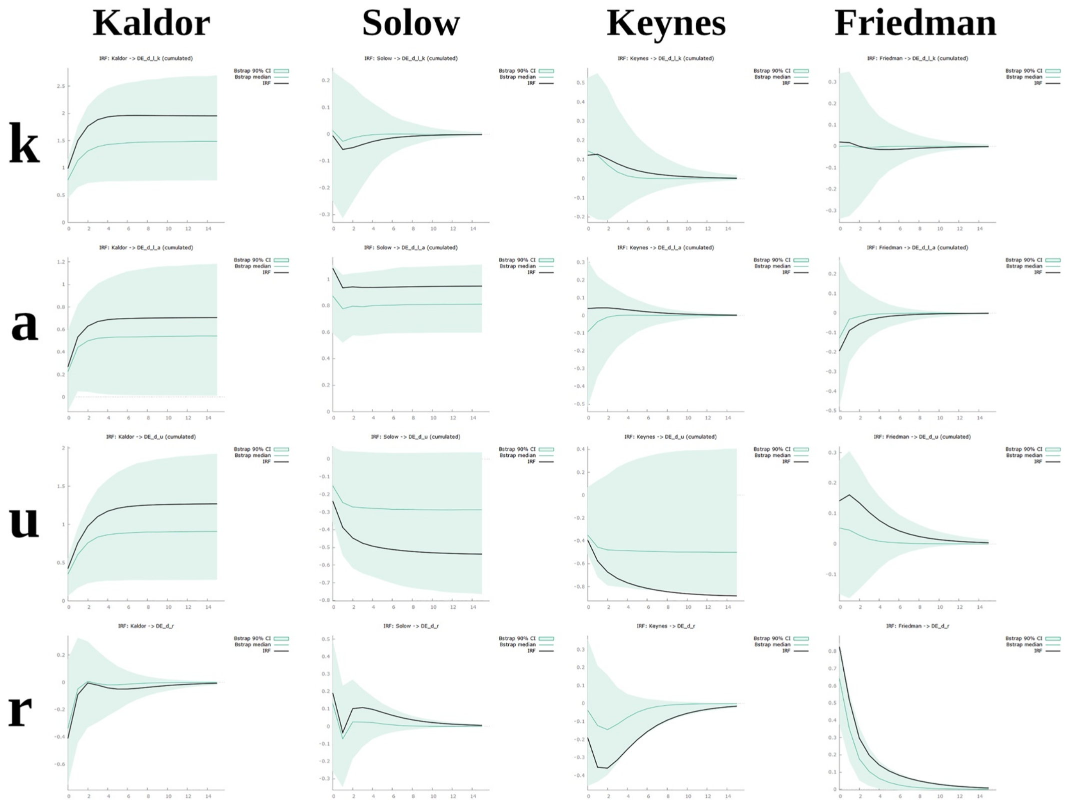


**FIGURE 4** Response to structural one S.D. innovations ±2 S.E. for Germany.

hand, the unemployment rate tends to increase in Spain (0.40), Italy (0.24) and the UK (0.04). In these countries, technological advancements tend to generate technological unemployment. Finally, the real interest rate increases or decreases in response to technology shock following the business cycle.

### *Demand shocks a la Keynes*

A Keynesian positive aggregate demand shock is modeled in the VAR through a reduction in the *unemployment rate*. It is important to note that although the initial increase in demand is temporary, the overall effect after 10–12 periods is permanent in all the countries analyzed (with the only exception of Finland). Following a positive demand shock the equilibrium unemployment rate tends to decline, reaching a new steady state lower than the initial one. This effect occurs (significantly) in all economies and is particularly relevant in Greece (with a long-run multiplier of −1.50), Spain (−1.15), Netherlands (−0.97) and Germany (−0.89). This fact is consistent with the Keynesian vision that the expansion of aggregate demand reduces unemployment. Note, however, that in our analysis, this happens not only in the short but also in the long run: equilibrium unemployment drops immediately and converges towards a lower steady state after 6–10 periods. Obviously, the effect of the demand shock on (un)employment depends on the elasticity of substitution between capital and labor along time. For instance, a positive demand shock can affect the composition of total employment if firms vary the extensive and the intensive margin of labor utilization. In addition, the cost of adjusting employment can become affordable if firms expect the shock to have lasting consequences on aggregate demand (Galí & Van Rens, 2021). Similar considerations can explain the responses of TFP to a positive demand shock. TFP increases immediately after the demand shock (especially in Austria,

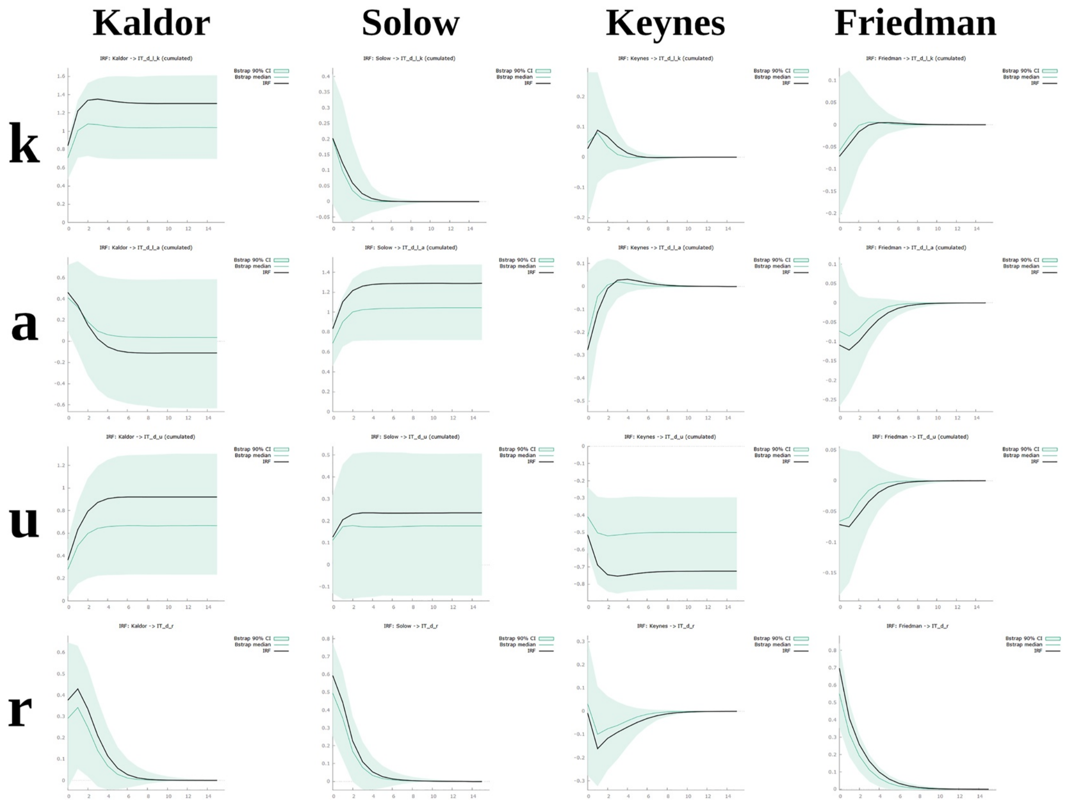


**FIGURE 5** Response to structural one S.D. innovations ±2 S.E. for Italy.

Portugal, and the US), but the induced effect is reabsorbed after 6–12 periods. Finally, the demand shock leads to an increase in the real interest rate in many countries. This response confirms the result of Donaldson et al. (1990) that the real interest rate is pro-cyclical in contrast to the neoclassical view (Seppala, J. (2004)). As expected, this effect fades over time.

*Monetary shocks a la Friedman*

Finally, we focus on monetary shocks. In response to a one-time drop in the real interest rate, economic variables adjust quickly before returning to their equilibrium value. The whole process happens (on average) within 4 years. Only exceptionally do the effects of the same shocks last longer, and in any case, they never exceed 8–10 periods in total. The response to this shock is quantitatively stronger in Finland, Greece, Netherland and Sweden, while it is significantly smaller in the case of Belgium, Germany and Luxembourg. In these countries, together with Spain, the fluctuation occurs gradually and takes up to 10 periods before it disappears. Consistent with economic theory, this kind of shock has transitory effects on the variables in the model. Specifically, a positive demand response coming from the interest rate shock has a temporary (positive) effect on *capital intensity* and *productivity*. Both variables increase in the short run and then return to their long-run path as time passes. Note that in some cases the initial shock may give rise to countercyclical effects. This happens for instance in Belgium, Denmark, Finland and Ireland. However, after an initial negative trough, both $k$ and $a$ rise rapidly before settling on the new equilibrium. Finally, the effect on the *unemployment rate* is generally negative and rapid. It declines in 10 of the 17 countries. The effect

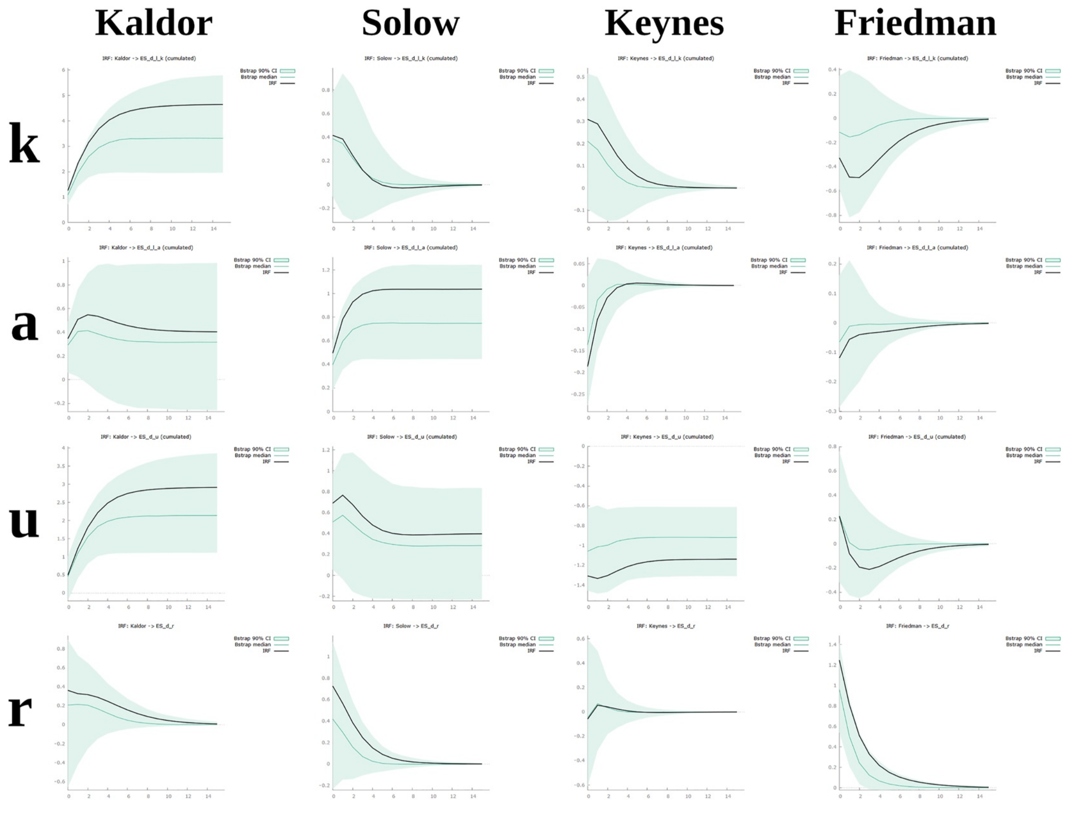


FIGURE 6 Response to structural one S.D. innovations ±2 S.E. for Spain.

is stronger in Belgium, Finland, Italy, and Portugal, while it is rather weak in Spain and Sweden. Moreover, in most cases the response to the initial shock disappears quickly, while in some countries it can take up to 8–10 years.

The forecast error variance (FEVDs) and the historical decompositions (HDs) are discussed in the Online Appendix (Section B). While the former allows to identify the proportion of the variation in the time series due to their "own" shocks versus shocks to the other variables, the latter is used to determine the importance of single shocks in driving the pattern of endogenous variables in each specific year. The two decompositions confirm the dynamic scenarios outlined above.

## 5 | CONCLUSIONS

In this paper we present a model of economic growth with endogenous technical progress. We test if the neoclassical growth framework accepts the Kaldorian idea that capital intensity affects technical progress in the long run. To this aim, we study the dynamic responses of capital intensity, total factor productivity, unemployment rate, and real interest rate to four structural shocks in 17 advanced economies, over the period 1980–2020. The structural shocks are identified by imposing long-run restrictions on the multipliers of the estimated VAR.

The theoretical framework we propose is simple, but formal, in order to derive in continuity the SVAR model. It is important to underline that the use of a two-sector model is not a novelty

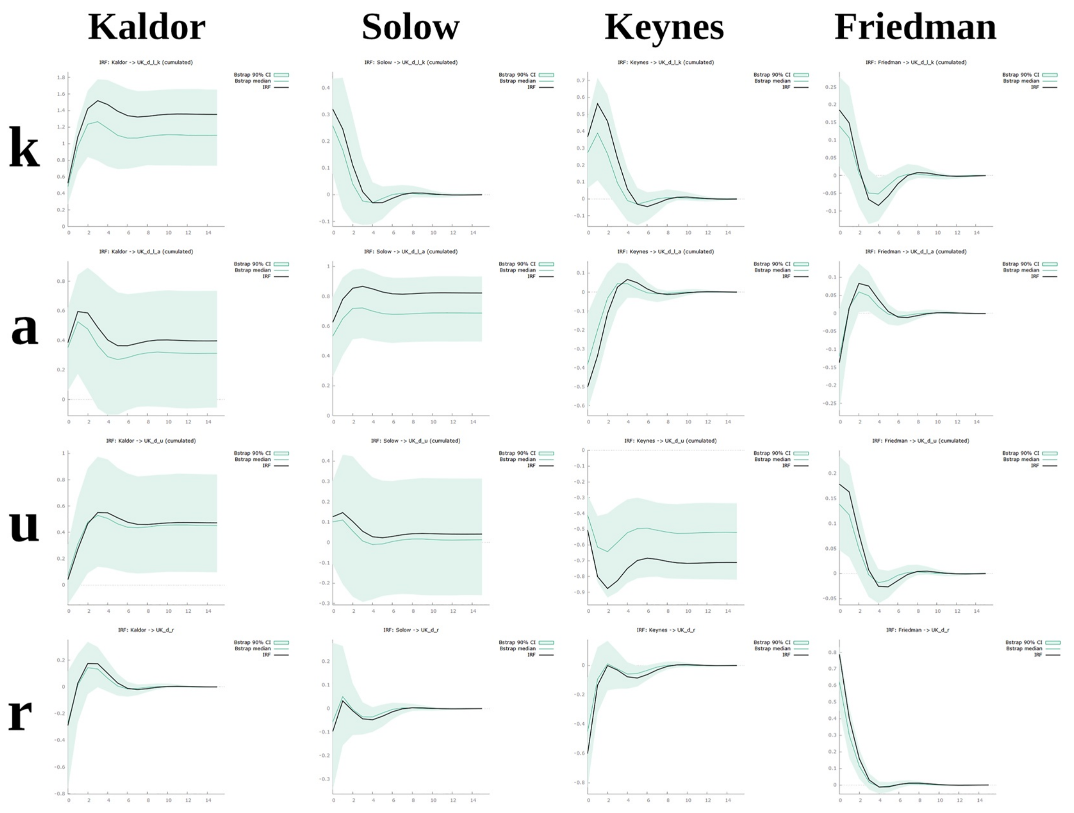


**FIGURE 7** Response to structural one S.D. innovations ±2 S.E. for the UK.

in the literature on endogenous growth. The main difference with respect to learning-by-doing by Arrow (1962), the model with endogenous saving and learning- by-doing by Romer (1986, 1990), the model with human capital by Lucas (1988) is that in Equation (1) we assume that the technology advancement strictly depends on *labor productivity* other that inventiveness. This assumption must not appear as an ad hoc hypothesis, but rather the reflection of the *new* stylized facts of economic growth, over last decades, which show that labor productivity is strictly correlated with changes in capital intensity along with innovation. Obviously, our approach relaunches the Kaldorian point of view according to which technical progress must be seen as intrinsically related to the dynamics of capital intensity.

To resume, from our analysis emerges that movements along the production function cannot be distinguished from shifts in this function, and that a positive relationship between capital intensity and technical progress exists in the long run, so that TFP cannot be treated as an *exogenous* input as in the standard neoclassical model. The main implication of this result is that interpreting the growth accounting relationships, from the Solow perspective, as causal, may *understate* the contribution of capital intensity to economic growth (Aghion & Howitt, 2009). This corroborates the suspect of Jorgenson and Griliches (1967) that careful measurement of the relevant input variables would cause the Solow residual to disappear.

Some policy implications can be derived from our analysis. Investments and inventiveness increase steadily technical progress. However, such changes may have an adverse, even if temporary, effect on the (un)employment during the transition from one equilibrium to another. This may lead to phases of technological unemployment or to "temporary phase of maladjustment" (Keynes, 1930). In this

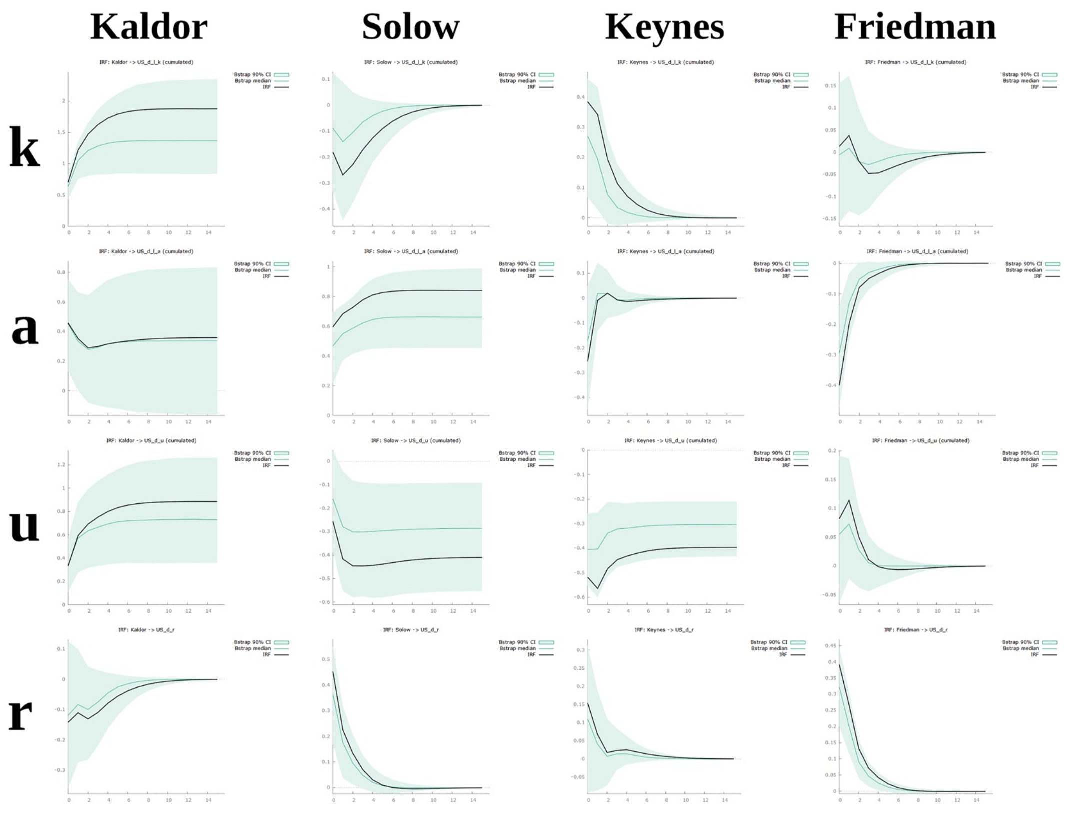


**FIGURE 8** Response to structural one S.D. innovations ±2 S.E. for the US.

perspective, monetary policy can help to support employment over the cycle, while fiscal policy can tackle the potential (net) negative effects of unemployment, even in the long run. Hence, aggregate demand policy can improve steadily the level of employment. Obviously, these results would suggest rethinking the rules of European fiscal policy, considering the current discussions on the Stability and Growth Pact.

Finally, our framework sheds new lights on Kaldor's studies aimed at building a bridge between the short and the long run components of economic growth. Probably, Kaldor was ahead of his time and proposed theoretical reinterpretations of economic theories that seemed irreconcilable to his contemporaries.[17] Today, this step seems outdated, also in the light of the endogenous growth models. If, as our analysis documents, technical progress strictly depends on capital intensity, neoclassical TFP can no longer be interpreted as the measure of *exogenous technical progress*. Any effort in relaunching productivity and employment cannot be disjoint from investment decisions.

## ACKNOWLEDGMENTS

This article has greatly benefited from the guidance of two anonymous referees and useful comments from one of the editors of Metroeconomica. We also thank the Cambridge University Library for the rare papers provided for this study.

[17]As recalled by Hahn (1989), "even now, one must conclude that (Kaldor) was more interesting and adventurous than the rest of us who stuck to the straight and narrow of neoclassical theory".

## CONFLICT OF INTEREST STATEMENT

The authors declares no conflict of interest.

## DATA AVAILABILITY STATEMENT

An online appendix with data description and additional results is available.

## DISCLAIMER STATEMENT

Usual disclaimer applies.

## REFERENCES

Abramovitz, M. (1956). Resource and output trends in the United States since 1870. In *Resource and output trends in the United States since 1870* (Vol. *52*, pp. 1–23). NBER Occasional Papers.

Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, *60*(2), 323–351. https://doi.org/10.2307/2951599

Aghion, P., & Howitt, P. W. (2009). *The economics of growth*. MIT press.

Antenucci, F., Deleidi, M., & Paternesi Meloni, W. (2020). Kaldor 3.0: An empirical investigation of the Verdoorn-augmented technical progress function. *Review of Political Economy*, *32*(1), 49–76. https://doi.org/10.1080/09538259.2020.1744936

Arrow, K. J. (1962). The economic implications of learning by doing. *The Review of Economic Studies*, *29*(3), 155–173. https://doi.org/10.2307/2295952

Bairam, E. I. (1987). Returns to scale, technical progress and output growth in branches of industry: The case of Soviet Republics, 1962-74. *Scottish Journal of Political Economy*, *34*(3), 249–266. https://doi.org/10.1111/j.1467-9485.1987.tb00283.x

Ball, L. (2009). *Hysteresis in unemployment: Old and new evidence* (NBER Working Paper No. 14818, pp. 1–37). National Bureau of Economic Research. https://doi.org/10.3386/w14818

Balmaseda, M., Dolado, J. J., & Lopez-Salido, J. D. (2000). The dynamic effects of shocks to labour markets: Evidence from OECD countries. *Oxford Economic Papers*, *52*(1), 3–23. https://doi.org/10.1093/oep/52.1.3

Basu, D., & Budhiraja, M. (2021). What to make of the Kaldor-Verdoorn law? *Cambridge Journal of Economics*, *45*(6), 1243–1268. https://doi.org/10.1093/cje/beab027

Basu, S., Fernald, J. G., & Kimball, M. S. (2006). Are technology improvements contractionary? *The American Economic Review*, *96*(5), 1418–1448. https://doi.org/10.1257/aer.96.5.1418

Bellocchi, A., Sanchez Carrera, E., & Travaglini, G. (2021). Asymmetries in the euro area and TFP growth: Evidence from three major European economies. *Journal of Economics Studies*, *48*(5), sa945–967.

Bernanke, B. S. (1986). Alternative explanations of the money-income correlation. *Carnegie-Rochester Conference Series On Public Policy*, *25*(1), 49–99. https://doi.org/10.1016/0167-2231(86)90037-0

Black, J. (1962). The technical progress function and the production function. *Economica*, *29*(114), 166–170. https://doi.org/10.2307/2551552

Blanchard, O., Cerutti, E., & Summers, L. (2015). *Inflation and activity - two explorations and their monetary policy implications*. National Bureau of Economic Research (NBER) WP, No. w21726.

Blanchard, O. J., & Quah, D. (1989). The dynamic effects of aggregate demand and supply disturbances. *NBER Working Papers*, *2737*.

Blanchard, O. J., & Summers, L. H. (1986). Hysteresis and the European unemployment problem. NBER chapters. *NBER Macroeconomics Annual*, *1*, 15–90. https://doi.org/10.1086/654013

Blanchard, O. J., & Watson, M. W. (1986). Are business cycles all alike? NBER chapters. In *The American business cycle: Continuity and change* (pp. 123–180).

Bugamelli, M.o, et al. (2018). Productivity growth in Italy: A tale of a slow-motion change. *Bank of Italy Occasional Paper*, *422*.

Carnevali, E., Godin, A., Lucarelli, S., & Passarella, M. V. (2020). Productivity growth, Smith effects and Ricardo effects in Euro Area's manufacturing industries. *Metroeconomica*, *71*(1), 129–155. https://doi.org/10.1111/meca.12270

Chow, G. C. (1960). Tests of equality between sets of coefficients in two linear regressions. *Econometrica*, *28*(3), 591–605. https://doi.org/10.2307/1910133

Cirillo, V., Fanti, L., Mina, A., & Ricci, A. (2022). New digital technologies and firm performance in the Italian economy. *Industry & Innovation*, *30*(1), 159–188. https://doi.org/10.1080/13662716.2022.2055999

Clarida, R., & Gali, J. (1994). Sources of real exchange-rate fluctuations: How important are nominal shocks? *Carnegie-Rochester Conference Series On Public Policy*, *41*(1), 1–56. https://doi.org/10.1016/0167-2231(94)00012-3

Crafts, N., & Woltjer, P. (2021). Growth accounting in economic history: Findings, lessons and new directions. *Journal of Economic Surveys*, *35*(3), 670–696. https://doi.org/10.1111/joes.12348

David, P. A. (1986). *Technology diffusion, public policy, and industrial competitiveness.The positive sum strategy: Harnessing technology for economic growth*. National Academies Press.

Deleidi, M., Paternesi, W. M., Stirati, A., & Tosi, F. (2021). Output, investment and productivity: The Italian north–south regional divide from a Kaldor–Verdoorn approach. *Regional Studies*, *55*(8), 1376–1387. https://doi.org/10.1080/00343404.2021.1896694

Donaldson, J. B., Johnsen, T., & Mehra, R. (1990). On the term structure of interest rates. *Journal of Economic Dynamics and Control*, *14*(3), 571–596. https://doi.org/10.1016/0165-1889(90)90034-e

ECB. (2018). Economic bulletin.2.

Eltis, W. A. (1971). The determination of the rate of technical progress. *Economic Journal*, *81*(323), 502–524. https://doi.org/10.2307/2229846

Fazzari, S. M., Ferri, P., & Variato, A. M. (2020). Demand-led growth and accommodating supply. *Cambridge Journal of Economics*, *44*(3), 583–605. https://doi.org/10.1093/cje/bez055

Felipe, J., & McCombie, J. S. L. (2007). Is a theory of total factor productivity really needed? *Metroeconomica*, *58*(1), 195–229. https://doi.org/10.1111/j.1467-999x.2007.00265.x

Galí, J., & Van Rens, T. (2021). The vanishing procyclicality of labour productivity. *The Economic Journal*, *131*(633), 302–326. https://doi.org/10.1093/ej/ueaa065

Gamber, E. N., & Joutz, F. L. (1993). The dynamic effects of aggregate demand and supply disturbances: Comment. *The American Economic Review*, *83*(5), 1387–1393.

Goldin, I., Pantelis, K., François, L., & Julian, W. (2020). *Why is productivity slowing down?* MPRA Paper, University Library of Munich.

Gordon, R. J. (2017). *The rise and fall of American growth: The US standard of living since the civil war*. Princeton University Press.

Grass, D., Hartl, R. F., & Kort, P. M. (2012). Capital accumulation and embodied technical progress. *Journal of Optimization Theory and Applications*, *154*(2), 588–614. https://doi.org/10.1007/s10957-012-0042-5

Green, H. A. J. (1960). Growth models, capital and stability. *Economic Journal*, *70*(277), 57–73. https://doi.org/10.2307/2227482

Griliches, Z., & Jorgenson, J. (1966). Sources of measured productivity change: Capital input. *The American Economic Review*, *56*, 50–61.

Grossman, G. M., & Helpman, E. (1991). Trade, knowledge spillovers, and growth. *European Economic Review*, *35*(2–3), 517–526. https://doi.org/10.1016/0014-2921(91)90153-a

Gundlach, E. (2005). Solow vs. Solow: Notes on identification and interpretation in the empirics of growth and development. *Review of World Economics*, *141*(3), 541–556. https://doi.org/10.1007/s10290-005-0042-8

Hahn, F. H. (1989). Kaldor on growth. *Cambridge Journal of Economics*, *13*(1), 47–57. Oxford University Press.

Hahn, F. H., & Matthews, R. C. (1964). The theory of economic growth: A survey. *Economic Journal*, *74*(196), 779–902. https://doi.org/10.2307/2228848

Hicks, J. (1980). IS-LM: An explanation. *Journal of Post Keynesian Economics*, *3*(2), 139–154. https://doi.org/10.1080/01603477.1980.11489209

Jarrett, P., & Torres, R. (1987). A revised supply block for the major seven countries. *OECD Economics Department Working Papers*, *41*. OECD Publishing.

Johansen, L. (1959). Substitution versus fixed production coefficients in the theory of economic growth: A synthesis. *Econometrica*, *27*(2), 157–176. https://doi.org/10.2307/1909440

Johansen, S. (1995). *Likelihood-based inference in cointegrated vector autoregressive models*. Oxford University Press.

Jorgenson, D. W., & Griliches, Z. (1967). The explanation of productivity change. *The Review of Economic Studies*, *34*(3), 349–383. https://doi.org/10.2307/2296675

Juselius, K. (2006). *The cointegrated VAR model: Methodology and applications*. Oxford university press. Also, the year of the citation in the main text must be updated to 2006.

Kaldor, N. (1957). A model of economic growth. *The Economic Journal*, *67*(268), 591–624. https://doi.org/10.2307/2227704

Kaldor, N. (1960). *Essays on stability and growth*. DuckWorth and Co.

Kaldor, N. (1961). Capital accumulation and economic growth. In D. C. Hague (Ed.), *The theory of capital. International economic association series*. Palgrave Macmillan.

Kaldor, N. (1966). *Causes of the slow rate of economic growth in the UK. Inaugural Lecture*. Cambridge University Press.

Kaldor, N. (1970). The case for regional policies. *Scottish Journal of Political Economy*, *17*(3), 337–348. https://doi.org/10.1111/j.1467-9485.1970.tb00712.x

Kaldor, N. (1972). The irrelevance of equilibrium economics. *Economic Journal*, *328*, 1237–1255. https://doi.org/10.2307/2231304

Kaldor, N. (1981). The role of increasing returns, technical progress and cumulative causation in the theory of international trade and economic growth. *Economie Appliquee*, *34*(4), 593–617.

Kaldor, N., & Mirrlees, J. A. (1962). A new model of economic growth. *The Review of Economic Studies*, *29*(3), 174–192. https://doi.org/10.2307/2295953

Keynes, J. M. (1930). Economic possibilities for our grandchildren (1930). In *Essays in persuasion* (pp. 358–373). Harcourt Brace.

Keynes, J. M. (1936). *The general theory of employment, interest and money*. Macmillan.

Keynes, J. M., & Kaldor, N. (1937). Prof. Pigou on money wages in relation to unemployment. *The Economic Journal*, *47*(188), 743–753. https://doi.org/10.2307/2225349

Kulendran, N., & Witt, S. F. (2001). Cointegration versus least squares regression. *Annals of Tourism Research*, *28*(2), 291–311. https://doi.org/10.1016/s0160-7383(00)00031-1

Lazonick, W., & Brush, T. (1985). The horndal effect in early US manufacturing. *Explorations in Economic History*, *22*(1), 53–96. https://doi.org/10.1016/0014-4983(85)90021-x

Licandro, O. (2022). *Innovation and growth: Theory.macroeconomic modelling of R&D and innovation policies*. Springer Nature.

Lucas, R. J. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, *22*(1), 3–42. https://doi.org/10.1016/0304-3932(88)90168-7

Maestas, N., Mullen, K. J., & Powell, D. (2016). *The effect of population aging on economic growth, the labour force and productivity*. National Bureau of Economic Research WP, No. w22452.

Mankiw, N. G. (1995). The growth of nations, brookings papers on economic activity (pp. 275–325).

Mankiw, N. G. (1997). Comment. In B. S. Bernanke & J. Rotemberg (Eds.), *NBER macroeconomics annual 1997* (pp. 103–107). MIT Press.

Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A contribution to the empirics of economic growth. *Quarterly Journal of Economics*, *107*(2), 407–437. https://doi.org/10.2307/2118477

McCombie, J., & Spreafico, M. R. (2016). Kaldor's 'technical progress function' and Verdoorn's law revisited. *Cambridge Journal of Economics*, *40*(4), 1117–1136. https://doi.org/10.1093/cje/bev030

Meier, G. M. (2001). The old generation of development economists and the new. In G. M. Meier & J. E. Stiglitz (Eds.), *Frontiers of development economics*. World Bank and Oxford University Press.

Nah, W. J., & Lavoie, M. (2019). Convergence in a neo-Kaleckian model with endogenous technical progress and autonomous demand growth. *Review of Keynesian Economics*, *7*(3), 275–291. https://doi.org/10.4337/roke.2019.03.01

Ollivaud, P., & Turner, D. (2015). The effect of the global financial crisis on OECD potential output. *OECD Journal: Economic Studies*, *14*(1), 41–60. https://doi.org/10.1787/eco_studies-2014-5js64l2bv0zv

Palley, T. (2019). Unemployment and growth: Putting unemployment into Post Keynesian growth theory. *Review of Political Economy*, *31*(2), 194–215. https://doi.org/10.1080/09538259.2019.1644729

Perron, P. (1989). The Great crash, the oil price shock, and the unit root hypothesis. *Econometrica, Econometric Society*, *57*(6), 1361–1401. https://doi.org/10.2307/1913712

Pissarides, C. A., & Vallanti, G. (2007). The impact of TFP growth on steady-state unemployment. *International Economic Review*, *48*(2), 607–640. https://doi.org/10.1111/j.1468-2354.2007.00439.x

Prescott, E. C. (1998). Lawrence R. Klein lecture 1997: Needed: A theory of total factor productivity. *International Economic Review*, *39*(3), 525–551. https://doi.org/10.2307/2527389

Prescott, E. C. (2004). *Why do Americans work so much more than Europeans?* National Bureau of Economic Research (NBER) WP, 10316.

Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy*, *94*(5), 1002–1037. https://doi.org/10.1086/261420

Romer, P. M. (1989). *Human capital and growth: Theory and evidence* (NBER Working Paper No. 3173, pp. 1–51). National Bureau of Economic Research. https://doi.org/10.3386/w3173

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, *98*(5), S71–S102. Part 2. https://doi.org/10.1086/261725

Romer, P. M. (1994). The origins of endogenous growth. *The Journal of Economic Perspectives*, *8*(1), 3–22. https://doi.org/10.1257/jep.8.1.3

Saltari, E., & Travaglini, G. (2008). Il rallentamento della produttività del lavoro e la crescita dell'occupazione. Il ruolo del progresso tecnologico e della flessibilità del lavoro. *Rivista Italiana degli Economisti*, *13*(1), 3–38.

Saltari, E., & Travaglini, G. (2009). The productivity slowdown puzzle. Technological and non-technological shocks in the labour market. *International Economic Journal*, *23*(4), 483–509. https://doi.org/10.1080/10168730903377819

Schlicht, E. (2016). Directed technical change and capital deepening: A reconsideration of Kaldor's technical progress function. *Metroeconomica*, *67*(1), 119–151. https://doi.org/10.1111/meca.12101

Seppala, J. (2004). The term structure of real interest rates: Theory and evidence from UK index-linked bonds. *Journal of Monetary Economics*, *51*(7), 1509–1549. Elsevier. https://doi.org/10.1016/j.jmoneco.2004.01.002

Setterfield, M. (1993). A model of institutional hysteresis. *Journal of Economic Issues*, *27*(3), 755–774. https://doi.org/10.1080/00213624.1993.11505453

Setterfield, M. (2002). A model of Kaldorian traverse: Cumulative causation, structural change and evolutionary hysteresis. In *The economics of demand-led growth: Challenging the supply-side vision of the lon run* (pp. 215–233). Edward Elgar.

Shapiro, M. D., & Watson, M. W. (1988). Sources of business cycle fluctuations. In O. J. Blanchard & S. Fischer (Eds.), *NBER macroeconomics annual* (pp. 111–148). M.I.T. Press.

Sims, C. A. (1986). Are forecasting models usable for policy analysis? Quarterly review. *Federal Reserve Bank of Minneapolis*, *10*(Win), 2–16.

Solow, R. M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, *70*(1), 65–94. https://doi.org/10.2307/1884513

Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, *39*(3), 312. https://doi.org/10.2307/1926047

Solow, R. M. (1960). Investment and technical progress. In K. Arrow, S. Karlin, & P. Suppes (Eds.), *Mathematical methods in the social sciences* (pp. 89–104). Stanford University Press.

Storm, S. (2022). The secular stagnation of productivity growth. In *Handbook of economic stagnation* (pp. 37–58). Academic Press.

Swan, T. W. (1956). Economic growth and capital accumulation. *The Economic Record*, *32*(2), 334–361. https://doi.org/10.1111/j.1475-4932.1956.tb00434.x

Targetti, F. (1992). *Nicholas Kaldor: The economics and politics of capitalism as a dynamic system*. Oxford University Press.

Thirlwall, A. P. (1987). Nicholas Kaldor (1908-1986). *Moneta e Credito*, *30*(160), 479–512.

Travaglini, G., & Bellocchi, A. (2018). How supply and demand shocks affect productivity and unemployment growth: Evidence from OECD countries. *Economia Politica*, *35*(3), 955–979. https://doi.org/10.1007/s40888-018-0127-1

Verdoorn, P. J. (1949). Fattori che regolano lo sviluppo della produttività del lavoro. *L'Industria*, *1*, 45–53.

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Bellocchi, A., Travaglini, G., & Vitali, B. (2023). How capital intensity affects technical progress: An empirical analysis for 17 advanced economies. *Metroeconomica*, 1–26. https://doi.org/10.1111/meca.12421